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08/27/98

10447-1-8, PTO

UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	8498-027-999	Total Pages	20
First Named Inventor or Application Identifier			
JIMMY R. ROEHRIG			
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08/27/98
10447-1-8, PTO

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Assistant Commissioner
Box Patent Application
Washington, DC 20231

- ☒ Fee Transmittal Form
Submit an original, and a duplicate for fee processing)
- ☒ Specification [Total Pages 20]
(preferred arrangement set forth below)
-Descriptive title of the Invention
-Cross Reference to Related Applications
-Statement Regarding Fed sponsored R&D
-Reference to Microfiche Appendix
-Background of the Invention
-Brief Summary of the Invention
-Brief Description of the Drawings *(if filed)*
-Detailed Description of the Invention (including drawings, *if filed*)
-Claim(s)
-Abstract of the Disclosure
- ☒ Drawings (35 USC 113) [Total Sheets 4]
- ☒ Oath or Declaration unexecuted [Total Sheets 2]
 - ☐ Newly executed (original or copy)
 - ☐ Copy from a prior application (37 CFR 1.63(d))
(for continuation/divisional with Box 17 completed)
[Note Box 5 below]
 - ☐ DELETION OF INVENTOR(S)
Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33 (b).
- ☐ Incorporation By Reference *(useable if Box 4b is checked)*
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

- ☐ Microfiche Computer Program *(Appendix)*
- ☐ Nucleotide and/or Amino Acid Sequence Submission *(if applicable, all necessary)*
 - ☐ Computer Readable Copy
 - ☐ Paper Copy (identical to computer copy)
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ACCOMPANYING APPLICATION PARTS

- ☐ Assignment Papers (cover sheet & document(s))
- ☐ 37 CFR 3.73(b) Statement ☐ Power of Attorney *(when there is an assignee)*
- ☐ English Translation Document *(if applicable)*
- ☐ Information Disclosure ☐ Copies of IDS Statement (IDS)/PTO-1449 Citations
- ☐ Preliminary Amendment
- ☒ Return Receipt Postcard (MPEP 503)
(Should be specifically itemized)
- ☐ Small Entity ☐ Statement filed in prior application, Statement(s) Status still proper and desired
- ☐ Certified Copy of Priority Document(s) *(if foreign priority is claimed)*
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17. If a CONTINUING APPLICATION, check appropriate box and supply the requisite information:

☐ Continuation ☐ Divisional ☒ Continuation-in-part (CIP) of prior application No: 09/103,290 filed June 23, 1998 which is a continuation of application no. 08/676,660 filed July 10, 1996.

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ATTORNEY DOCKET NO. 8498-027-999Date August 27, 1998

Assistant Commissioner for Patents
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Sir:

The following utility patent application is enclosed for filing:

Applicants: Jimmy R. ROEHRIG, Takeshi DOI, Nico
KARSSEMEIJER, Guido M. te BRAKE

Executed on: Unexecuted

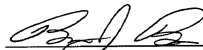
Title of Invention: METHOD AND SYSTEM FOR DETECTION OF SUSPICIOUS LESIONS IN DIGITAL
MAMMOGRAMS USING A COMBINATION OF SPICULATION AND DENSITY SIGNALS

PATENT APPLICATION FEE VALUE

TYPE	NO. FILED	LESS	EXTRA	EXTRA RATE	FEE
Total Claims	20	-20	0	\$22.00 each	0.00
Independent	3	-3	0	\$82.00 each	0.00
Minimum Fee					790.00
Multiple Dependency Fee If Applicable (\$270.00)					
Total					790.00
50% Reduction for Independent Inventor, Nonprofit Organization or Small Business Concern (a verified statement as to the applicant's status is attached)					- 395.00
Total Filing Fee					\$ 395.00

- ☒ Priority of application no. 09/103,290 filed on June 23, 1998 which is a continuation of U.S. Application No. 08/676,660 filed July 10, 1996 is claimed under 35 U.S.C. § 120.
- ☐ The certified copy of the priority application has been filed in application no. filed .
- ☐ Amend the specification by inserting before the first line the following sentence; This is a continuation-in-part of application no. filed .

Respectfully submitted,



Francis B. Morris
PENNIE & EDMONDS LLP

38,825 For: 24,615
(Reg. No.)

Enclosure

This form is not for use with continuation, divisional, re-issue, design or plant patent applications.

**METHOD AND SYSTEM FOR DETECTION OF
SUSPICIOUS LESIONS IN DIGITAL MAMMOGRAMS
USING A COMBINATION OF SPICULATION AND DENSITY SIGNALS**

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5

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S.

- 10 Patent Application Serial No. 09/103,290, entitled "Method
and Apparatus for Fast Detection of Spiculated Lesions in
Digital Mammograms," filed June 23, 1998, which is a
continuation of U.S. Patent Application Serial No.
08/676,660, filed July 10, 1996, for which a notice of
allowance was mailed on May 12, 1998 for which an issue fee
15 was paid on May 19, 1998. Both of the above applications are
assigned to the assignee of the present invention. The above
applications are hereby incorporated by reference into the
present application.

20

FIELD OF THE INVENTION

- The present invention relates to the field of computer
aided diagnosis of medical images. In particular, the
invention relates to a method and apparatus for detecting
25 suspicious lesions in digital mammograms using an algorithm
that independently computes mass information and spiculation
information for allowing faster and more reliable
identification of suspicious lesions.

30

BACKGROUND OF THE INVENTION

- Breast cancer in women is a serious health problem. The
American Cancer Society currently estimates that over 180,000
U.S. women are diagnosed with breast cancer each year.
Breast cancer is the second major cause of cancer death among
35 women. The American Cancer Society also estimates that
breast cancer causes the death of over 44,000 U.S. women each
year. While, at present, there is no means for preventing

breast cancer, early detection of the disease prolongs life expectancy and decreases the likelihood of the need for a total mastectomy. Mammography using x-rays is currently the most common method of detecting and analyzing breast tumors.

- 5 Detection of suspicious, i.e. possibly cancerous, areas in mammograms is an important first step in the early diagnosis and treatment of breast cancer. While it is important to detect suspicious lesions when they are in the early stages, practical considerations can make this
- 10 difficult. One complicating factor is that a typical mammogram may contain myriads of lines corresponding to fibrous breast tissue. The trained, focused eye of a medical professional, such as a radiologist, is needed to detect suspicious features among these lines. A typical radiologist
- 15 may be required to examine hundreds of mammograms per day, leading to the possibility of a missed diagnosis due to fatigue and human error.

- Recently, medical professionals have begun to use Computer Aided Diagnostic (CAD) tools to assist them in
- 20 detecting suspicious features. Experiments have shown that the performance of radiologists improves when they are assisted by detection software that marks suspicious areas. See Brake and Karssemeijer, "Detection of Stellate Breast Abnormalities," Digital Mammography pp. 341-346 (Elsevier
- 25 Science 1996), the contents of which are hereby incorporated by reference into the present disclosure.

- FIG. 1 shows a continuum of lesions that may appear in mammograms, ranging from a pure mass or pure density lesion on the left to a spiculated lesion on the right. Other
- 30 types of lesions include architectural distortions, which have radiating lines similar to spiculated lesions but are generally without a central mass, and radial scars, which appear as criss-crossed lines and also are generally without a central mass.

- 35 Sharply defined masses such as those shown at the left in FIG. 1 are rarely associated with malignant tumors, while spiculated masses can be a strong indication of malignancy.

Lesions having the characteristics of architectural distortions or radial scars may also be cancerous, depending on their size and shape.

- Accordingly, there is value in locating and analyzing
- 5 both the "mass" or "density" qualities and the "spiculatedness" qualities of shapes found in digital mammograms. CAD systems generally include "mass" (or density) focused algorithms and "spiculation" focused algorithms. Some algorithms attempt to use metrics of both
 - 10 "massness" and "spiculatedness" to identify suspicious portions of digital mammograms. Such algorithms are included among the following references: Yin and Giger et. al., "Computerized Detection of Masses in Digital Mammograms: Analysis of Bilateral Subtraction Images," Medical Physics, Vol. 18, No. 5, pp. 955-963 (Sept./Oct. 1991); Sahiner et. al., "Classification of Masses on Mammograms Using a Rubber-Band Straightening Transform and Feature Analysis," Medical Imaging, SPIE Symposium on Medical Imaging Paper No. 2710-06, at p. 204 (1996); and Huo and Giger et al., "Analysis of
 - 20 Spiculation in the Computerized Classification of Mammographic Masses," Medical Physics, Vol. 22, No. 10, pp. 1569-1579 (Oct. 1995). The contents of the above references are hereby incorporated by reference into the present application.
 - 25 Typical of the above algorithms, Huo and Giger take a serial and dependent approach by first identifying masses and subsequently identifying spiculatedness characteristics of those masses. Huo and Giger demonstrate how the edges of detected masses can be used to determine a measure of
 - 30 spiculation -- i.e., spiculatedness. Huo and Giger, approach the problem serially by first detecting the mass signature, or density, in a mammogram, and then applying various filtering analyses to filter out benign masses and false detections, such as parenchymal structure. The Huo and Giger
 - 35 approach initially depends on density, which is a feature with low positive predictive value. It then attempts to improve upon itself by measuring features with higher

- positive predictive values, such as spiculation. The shortcomings of the Huo/Giger approach include the fact that the additional feature measurements typically depend on secondary algorithms that may be non-robust. These secondary
- 5 algorithms may include algorithms for spiculation, region growing, or segmentation of the mass boundaries. Also, these algorithms may display poor sensitivity on architectural distortions and radial scars which have no central density. Finally, because the algorithm is inherently serial, wherein
- 10 the spiculation information is computed after the mass information, the time for completion of the algorithm is the sum of the time for completion of the mass detection algorithm plus the spiculation detection algorithm, which can lead to disadvantageously slow results.
- 15 A direct "backward direction" algorithm for of spiculation detection is disclosed in Karssemeijer, "Recognition of Stellate Lesions in Digital Mammograms," Digital Mammography: Proceedings of the 2nd International Workshop on Digital Mammography, York, England, 10-12 July, 1994, pp. 211-219 (Elsevier Science 1994), the contents of which are hereby incorporated by reference into the present application. By "backward direction" it is meant that a "candidate point" is incrementally moved across the image by a distance corresponding to the desired resolution of the
- 25 spiculation search. At each candidate point, a set of "window computations" for a window of pixels surrounding the candidate point is performed, and a metric corresponding to the presence and/or strength of a spiculation centered on the candidate point is computed.
- 30 "Backward direction" algorithms are computationally intensive. For an image size of $N \times N$ pixels, there generally need to be on the order of $K(bN)^2$ computations, where K is the number of window computations for each candidate point and b is the reciprocal of the number of
- 35 image pixels between each candidate point. Because the number K is often proportional to the square or cube of the window size, the computational intensity of "backward

direction" approaches can easily become unwieldy. Another example of a "backward direction" spiculation algorithm is described in Kegelmeyer, "Computer-aided Mammographic Screening for Spiculated Lesions," Radiology, Vol. 191, pp.

- 5 331-337 (1994), the contents of which are hereby incorporated by reference into the present application. The computational complexity of "backward direction" spiculation algorithms may cause a CAD program to be too slow for practical use by medical professionals, such as radiologists.
- 10 Additionally, a practical implementation of a CAD system using a backward direction algorithm for spiculation detection would lead to inevitable dependency between the mass and spiculation algorithms. This is because, due to its slowness, the spiculation algorithm could only be applied to
- 15 a subset of interesting regions of the digital mammogram image, the interesting regions being pointed out by the presence of masses from the mass detection algorithm.

- Accordingly, it would be desirable to provide a computer-assisted diagnosis (CAD) system for assisting in the
- 20 detection of suspicious lesions in medical images that has increased speed in computing the necessary mass information and spiculation information.

- It would be further desirable to provide a computer-assisted diagnosis (CAD) system that has greater reliability
- 25 in detecting suspicious lesions of a digital mammogram that have characteristics similar to those of architectural distortions, radial scars, and spiculated lesions having very small central masses.

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SUMMARY OF THE INVENTION

- These and other objects of the present invention are achieved by an improved CAD system that incorporates
- 5 independent measurements of mass and spiculation characteristics as taken from a digital mammogram image. In a preferred embodiment, a forward spiculation detection algorithm is incorporated that is executed separately from a mass detection algorithm, and that is not dependent on any
- 10 results from the mass detection algorithm. The step of computing spiculation information may be performed before, during, or after the step of computing mass information, but in a preferred embodiment is performed concurrently in time with the mass detection algorithm for optimal time
- 15 performance of the overall system.

- According to a preferred embodiment, after the mass information and spiculation information is determined, a classifier algorithm classifies locations in the digital mammogram according to their feature vectors, which comprise
- 20 the computed mass information and spiculation information. The classifier algorithm may incorporate any of a variety of classification algorithms known in the art, including linear classifier algorithms, quadratic classifier algorithms, K-nearest-neighbor classifier algorithms, decision tree
- 25 classifier algorithms, or neural network classifier algorithms. By way of non-limiting example, the classifier algorithm may classify locations into a two-category system including a "suspicious" category and a "normal" category.

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BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects, features and advantages of the present invention will be more readily apparent from the following detailed description of the invention in which:

- 5 FIG. 1 shows various types of lesions arranged in an order from pure mass to highly spiculated mass;
- FIG. 2A is an outside view of an illustrative computer aided diagnostic (CAD) system;
- FIG. 2B is a block diagram of an illustrative CAD
10 processing unit for use in the CAD system of FIG. 2A;
- FIG. 3 is a flowchart showing steps taken by a CAD system in accordance with a preferred embodiment;
- FIG. 4 is a flowchart showing further steps taken by a CAD system in accordance with a preferred embodiment.

15

DETAILED DESCRIPTION OF THE INVENTION

- FIG. 2A is an outside view of an illustrative computer aided diagnostic (CAD) system 100 for assisting in the identification of suspicious areas in mammograms according to
20 the preferred embodiment. CAD system 100 comprises a CAD processing unit 102 and a viewing station 104. In general, CAD processing unit 102 scans a developed x-ray mammogram 101 into a digital mammogram image, processes the image, and outputs a highlighted digital mammogram for viewing at
25 viewing station 104.

- FIG. 2B is a block diagram of CAD processing unit 102. In accordance with the invention, processing unit 102 is capable of performing a multiplicity of image processing algorithms designed to detect abnormalities such as
30 spiculation detection, mass detection, linear weighted comparisons and general mathematical comparisons, either serially or in parallel with the disclosed abnormality detection algorithms. Preferably, CAD processing unit 102 includes a digitizer 103, a central control unit 105, a
35 memory 108, a parallel processing unit 110, and I/O unit 112. Digitizer 103 illustratively is a scanner with 50 micron resolution.

Viewing station 104 is for conveniently viewing both the x-ray mammogram 101 on a backlighting station 120 and the output of the CAD processing unit 102 on a display device 118. The display device 118 may be, for example, a CRT 5 screen. The display device 118 typically shows a highlighted digital mammogram corresponding to the x-ray mammogram 101, the highlighted digital mammogram having information directing the attention of the radiologist to suspicious areas which may contain spiculation as determined by image 10 processing steps performed by the CAD processing unit 102. In one embodiment of the invention, the highlighted digital mammogram will have black or red circles circumscribing locations with suspected abnormalities. Since the x-ray mammogram 101 on backlighting station 120 and the digitized 15 mammogram on display device 118 are physically adjacent one another, one application of viewing station 104 is to use the digitized mammogram to direct the attention of the radiologist to the spiculated portions of the actual x-ray mammogram 101 itself.

20 It is to be appreciated that the CAD processing unit 102 is capable of performing other image processing algorithms on the digital mammogram in addition to or in parallel with the algorithms for detecting abnormalities in accordance with the preferred embodiment. In this manner, the radiologist may be 25 informed of several suspicious areas of the mammogram at once by viewing the display device 118, spiculation being one special type of suspicious area.

After the x-ray mammogram 101 passes through the CAD system 100, it undergoes processing similar to that currently 30 practiced in clinics. In addition, memory 108 of CAD processing unit 102 may be used in conjunction with I/O unit 112 to generate a permanent record of the highlighted digital mammogram described above, and/or may also be used to allow non-real-time viewing of the highlighted digital mammogram.

35 FIG. 3 is an overview showing steps performed by CAD processing unit 102 on the x-ray mammogram in accordance with a preferred embodiment. At step 302, the x-ray mammogram is

scanned in and digitized into a digital mammogram. The digital mammogram may be, for example, a 3000 x 4000 array of 12-bit gray scale pixel values. Such a digital mammogram would generally correspond to a typical 8" x 10" x-ray

5 mammogram which has been digitized at a 50 micron spatial resolution. Because a full resolution image such as the 3000 x 4000 image described above is not necessary for the effectiveness of the preferred embodiment, the image may be locally averaged, using steps known in the art, down to a

10 smaller size corresponding, for example, to a 200 micron spatial resolution. At such a resolution, a typical image would then be an M x N array of 12-bit gray scale pixel values, with M being near 900, for example, and N being near 1200, for example. In general, however, either the full

15 resolution image or the locally averaged image may be used as the original digital mammogram in accordance with the preferred embodiment.

At step 304, a spiculation detection algorithm is performed on the digital mammogram. At step 306 a mass

20 detection algorithm is run on the digital mammogram. In a preferred embodiment, steps 304 and 306 are carried out concurrently so as to optimize overall speed of the detection process. Also in a preferred embodiment, steps 304 and 306 are carried out independently, in that there is no data

25 dependence between them. According to a preferred embodiment, the spiculation detection step 304 does not require any final or intermediate outputs from the mass detection step 306, and the mass detection step 306 does not require any final or intermediate outputs from the

30 spiculation detection step 304. In addition to introducing the ability to make the overall algorithm faster, the independence of the mass detection and spiculation detection steps allows for increased detection of features characteristic of architectural distortions, radial scars,

35 and in general otherwise suspicious lesions that do not have a significant central mass that is detected by the mass detection algorithm.

- At step 308, a classifier algorithm is performed on feature vectors corresponding to locations in the digital mammogram. Each location in the digital mammogram has a corresponding feature vector, which can be defined as a set
- 5 of characteristics, including the "massness" metrics and "spiculatedness" metrics that were determined previously at steps 304 and 306. A classifier is an algorithm or system that labels a feature vector as belonging to a specific class, such as "suspicious/normal," "malignant/benign," etc.
- 10 Several types of classifiers exist in the art, including linear classifiers, quadratic classifiers, k-nearest-neighbor method classifiers, decision trees, and neural networks. As known in the art, classifiers are constructed using a data set of example vectors representing each class, called a
- 15 training set or learning set. *See generally* Brake & Karssemeijer, *supra*, and references cited therein. Finally, at step 312, the digital mammogram image and a list of suspicious lesions are sent to the viewing station 104 for display.
- 20 Many spiculation detection algorithms are known in the art. Any number of these spiculation detection algorithms may be used to accomplish step 304. For example, step 304 may be satisfied by running either a backward or a forward spiculation detection algorithm. However, backward
- 25 spiculation detection algorithms consume substantially more time, computer memory, and general resources than forward spiculation detection algorithms. For this reason, a preferred embodiment uses a forward spiculation detection algorithm. The information resulting from a spiculation
- 30 detection algorithm may include such details as the geometrical coordinates of mammographic areas likely to contain spiculations, the size of the spiculation, or the like.

In step 306 of FIG. 3, a mass detection algorithm is run

35 against the digitized mammogram. Importantly, step 306 is independent of step 304 in that the mass detection algorithm is run against the digitized mammogram without reference to

- the spiculation detection algorithm of step 304, or the results of the spiculation detection algorithm of step 304. The independent nature of steps 304 and 306 is important because it solves the problem of that prior art in which a
- 5 mass detection algorithm and a spiculation detection algorithm are serially applied. In the prior art, a mass detection algorithm is applied to the digitized image first so that areas with "density," or mass, can be identified. In this way, a mass detection algorithm making a "first cut"
- 10 singles out only areas that may contain suspicious masses. Next, a spiculation detection algorithm is applied only to those suspicious areas that may contain masses, rather than to the entire mammographic image. Thus, spiculated masses with low density may be overlooked.
- 15 The preferred embodiment solves the "first cut" problem of the prior art because both a spiculation detection algorithm, step 304, and a mass detection algorithm, step 306, are independently applied to the entire mammographic image. By applying both a spiculation detection algorithm
- 20 and a mass detection algorithm to the entire image, an increased number of suspicious areas are likely to be identified. For example, areas containing low density spiculated masses may be identified. Step 306 can be executed using any number of mass detection algorithms known
- 25 in the art.

FIG. 4 shows exemplary steps corresponding to the classification step 308 when a simple linear classifier method is used. The example of FIG. 4 is presented for clarity and completeness of disclosure, to allow the reader

30 to more fully comprehend the context of the preferred embodiment, and is not intended to limit the scope of the present invention. It is to be understood that any of a variety of classifiers can be used at step 308, each having certain advantages, disadvantages, and tradeoffs in terms of

35 training time, computation time, probability of false positives, probability of missed detection, and other factors. The method described herein has an advantage,

however, of simplicity and speed of training and computation time.

The classification method of FIG. 4 supposes the common result that the spiculation detection algorithm and the mass
5 detection algorithm produce a scalar spiculation metric f_s
and a scalar mass metric f_m , respectively, each having a value
normalized between 0 and 100, for example. Thus, for
example, a given location may have a scalar spiculation
metric f_s of 90, which would indicate a very high degree of
10 spiculatedness, and a scalar mass metric f_m of 5, which would
indicate a very faint or small mass. In this simple case,
the pair (f_s , f_m) forms the feature vector at each location.

At step 402, the scalar spiculation metric f_s and the
scalar mass metric f_m are each multiplied by weighting factors
15 a_s and a_m , respectively, and the weighted factors are added to
form a result. At step 404, the result from step 402 is
compared to a predetermined threshold C. If the result from
step 402 is greater than the predetermined threshold C, the
location is identified as "suspicious" at step 406.
20 Otherwise, the location is identified as "normal" at step
408. The choices for a_s , a_m , and C define the parameters for
the linear classifier algorithm of FIG. 4. Using methods
known in the art, these linear classifier parameters are
statistically preselected using a large training set of
25 feature vectors that are known to represent each class being
identified.

As known in the art, the parameters of the classifier
may be changed to achieve different levels of utility and
results. Even in the simple linear classifier example of
30 FIG. 4, it is readily observed that the predetermined
threshold C may be lowered to increase system sensitivity and
bring more mammograms to the attention of the radiologist.
This would, of course, have the negative impact of increasing
the overall number of mammograms and false positives that the
35 radiologist must analyze. Conversely, the predetermined
threshold C may be increased to decrease system sensitivity,
and would have the converse result of necessitating less

radiologist intervention while risking more missed diagnoses.

The linear classifier technique of FIG. 4 can be generalized and extended to include several feature vector metrics (f1, f2, f3, ...) and several weights (a1, a2, a3 . . .). Other feature vector metrics may include, for example, the "sphericity" and "eccentricity" metrics disclosed in the parent U.S. App. No. 09/103,290, *supra*.

It is also within the scope of the preferred embodiments to for the classifier to identify more than two classes. For example, a classifier may be constructed to form four sets -- "suspicious -- more spiculated"; "suspicious -- more density;" "suspicious -- similar density and spiculation", and "normal." One use of the multiple classes would be, for example, to place red triangles around "suspicious -- more density" locations on the CRT display 118, placing blue triangles around "suspicious - more spiculation" locations, and green squares around "suspicious -- similar density and spiculation" locations. In this manner, the radiologist would be made aware of different types of suspicious lesions in different ways.

An alternative embodiment uses a look up table to combine the independent information at each location in the digitized mammogram. The look up table might be a two dimensional matrix that indicates for numerical values of mass information on a first axis and spiculation information on a second axis whether the combination of mass information and spiculation information is suspicious.

Both linear classifiers and neural networks are types of classifiers. In order to be able to use a classifier, prior statistical knowledge about the digital mammograms is necessary. For example, see Brake and Karssemeijer, "Detection of Stellate Breast Abnormalities," Digital Mammography pp. 341-346 (Elsevier Science 1996). Other types of classifiers include the Bayes optimal classifier, quadratic classifiers, the *k*th-nearest neighbor classifier, and artificial neural networks, or the like. One skilled in

the art will know that any of these pattern classification systems could be used according to the preferred embodiments.

Once an abnormality is located, the preferred embodiment could be extended to advantageously create further

5 classification parameters to indicate areas according to probable seriousness or likelihood of locating a benign abnormality versus locating a malignant abnormality. Such a further classification step could assist the medical professional in decision making and prioritization.

10 Although preferred embodiments have been described with respect to a CAD system for detecting suspicious lesions in digital mammograms, those skilled in the art should be able to apply the preferred embodiments to any number of other computer aided diagnosis systems.

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CLAIMS

What is claimed is:

1. A method for automated detection of suspicious lesions
5 in a digital mammogram, comprising the steps of:
 computing mass information corresponding to the
 digital mammogram, said mass information having mass
 location information;
 independent of said step of computing mass
10 information, computing spiculation information
 corresponding to the digital mammogram, said spiculation
 information having spiculation location information; and
 identifying suspicious lesions in the digital
 mammogram using said mass information and said
15 spiculation information.
2. The method of claim 1, wherein said step of computing
 spiculation information is performed prior to or concurrently
 with said step of computing mass information.
- 20 3. The method of claim 2, wherein said spiculation
 information is computed from a set of information other than
 said mass information, for allowing faster and more reliable
 detection of suspicious lesions in the digital mammogram.
- 25 4. The method of claim 3, wherein said step of identifying
 suspicious lesions includes the step of using a classifier
 algorithm to classify a feature vector corresponding to at
 least one location in said digital mammogram, each feature
30 vector comprising that portion of said mass information and
 said spiculation information that corresponds to that
 location.
5. The method of claim 4, wherein said classifier algorithm
35 is used to classify feature vectors associated with each
 location in said digital mammogram.

6. The method of claim 4, wherein said classifier algorithm comprises a linear classifier algorithm.

7. The method of claim 4, wherein said classifier comprises
5 a quadratic classifier algorithm.

8. The method of claim 6, said mass information comprising a mass metric, said spiculation information comprising a spiculation metric, said mass metric and said spiculation
10 metric being scalar quantities, said linear classifier algorithm comprising the steps of:

weighting said mass metric by a first weight to produce a weighted mass metric;

weighting said spiculation metric by a second
15 weight to produce a weighted spiculation metric;
combining said weighted mass metric and said weighted spiculation metric to produce a result;
comparing said result to a predetermined threshold;
identifying the corresponding location as
20 suspicious if said result is greater than said predetermined threshold;

and

identifying the corresponding location as normal if
said result is not greater than said predetermined
25 threshold.

9. The method of claim 8, wherein said first weight, said second weight, and said predetermined threshold are determined using a training algorithm on a training set of digital mammograms, said training set comprising a plurality
30 of examples of suspicious lesions and a plurality of examples of normal breast structure.

10. A computer program product for directing a computing apparatus to automatically detect suspicious lesions in a
35 digital mammogram, thus permitting the suspicious lesions to be brought to the attention of a medical professional, said computer program product comprising:

- computer code for computing mass information corresponding to the digital mammogram, said mass information having mass location information;
- 5 computer code for computing, independent of the computation of said mass information, spiculation information corresponding to the digital mammogram, said spiculation information having spiculation location information; and
- 10 computer code for identifying suspicious lesions in the digital mammogram using said mass information and said spiculation information.

11. The computer program product of claim 10, wherein said spiculation information is computed prior to or concurrently

15 with said step of computing mass information.

12. The computer program product of claim 11, wherein said computer code for identifying suspicious lesions includes computer code for using a classifier algorithm to classify a

20 feature vector corresponding to at least one location in said digital mammogram, each feature vector comprising that portion of said mass information and said spiculation information that corresponds to that location.

25 13. The computer program product of claim 12, wherein said classifier algorithm is used to classify feature vectors associated with each location in said digital mammogram.

14. The computer program product of claim 13, said mass

30 information comprising a mass metric, said spiculation information comprising a spiculation metric, said mass metric and said spiculation metric being scalar quantities, said linear classifier algorithm comprising the steps of:

weighting said mass metric by a first weight to

35 produce a weighted mass metric;

weighting said spiculation metric by a second weight to produce a weighted spiculation metric;

combining said weighted mass metric and said weighted spiculation metric to produce a result; comparing said result to a predetermined threshold; identifying the corresponding location as suspicious if said result is greater than said predetermined threshold;

and
identifying the corresponding location as normal if said result is not greater than said predetermined threshold.

15. An automated system for detecting suspicious portions of a digitized mammogram, comprising:
means for computing mass information corresponding to the digitized mammogram, said mass information having mass location information;
means for computing spiculation information corresponding to the digitized mammogram independent of said mass information, said spiculation information having spiculation location information; and
means for classifying said mass information and said spiculation information for detecting the suspicious portions of the digital mammogram.
16. The automated system of claim 15, wherein said means for computing spiculation information computes said spiculation information prior to or substantially in parallel with a period in which said means for computing mass information computes said mass information.
17. The automated system of claim 16, wherein said means for computing spiculation information computes said spiculation information using data other than said mass information.
18. The automated system of claim 17, wherein said means for classifying comprises:

means for computing at least one combined classification parameter defined by a combination of said mass information and said spiculation information; and

- means for identifying values for which said at least one combined classification parameter corresponds to a suspicious portion of the digital mammogram.

19. The automated system of claim 17, wherein said means for classifying comprises means for implementing a neural network algorithm capable of identifying the suspicious portions of the digital mammogram using said mass information and said spiculation information.

20. The automated system of claim 18, wherein said means for classifying includes a look up table that is indexed according to scalar quantities associated with said mass information and said spiculation information.

ABSTRACT

A method and system for detecting suspicious portions of digital mammograms by using independently calculated mass and spiculation information is disclosed. The method is for use
5 in a computer aided diagnosis system that is designed to bring suspicious or possibly cancerous lesions in fibrous breast tissue to the attention of a radiologist or other medical professional. In a preferred embodiment, spiculation information and mass information are independently
10 calculated, with the computed spiculation information not being dependent on results of the mass information computation, thus leading to greater reliability. Systems according to a preferred embodiment also compute spiculation information either prior to, or concurrently with, the
15 computation of mass information, thus allowing increased overall system speed.

20

25

30

35

sharply defined border

irregular border

mostly density

mostly spiculated

spiculated

FIG. 1

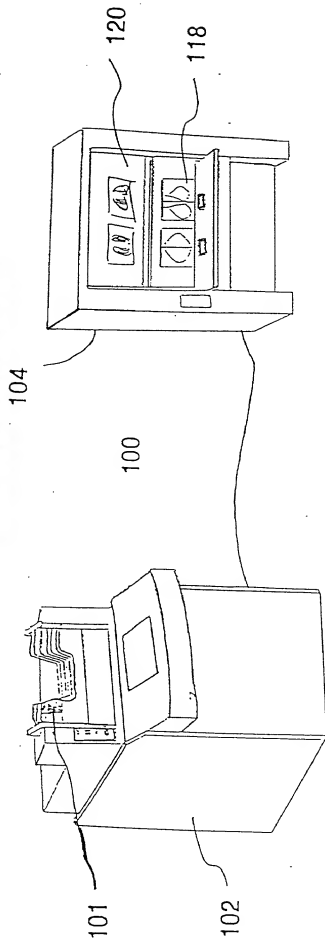


FIG. 2A

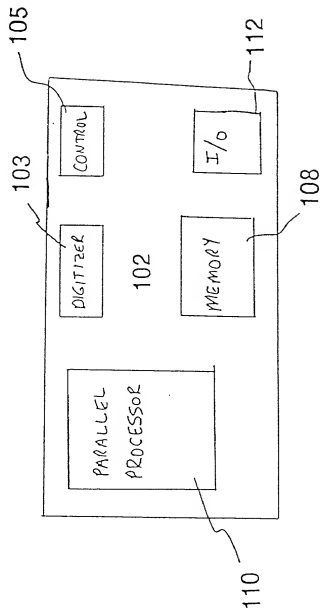


FIG. 2B

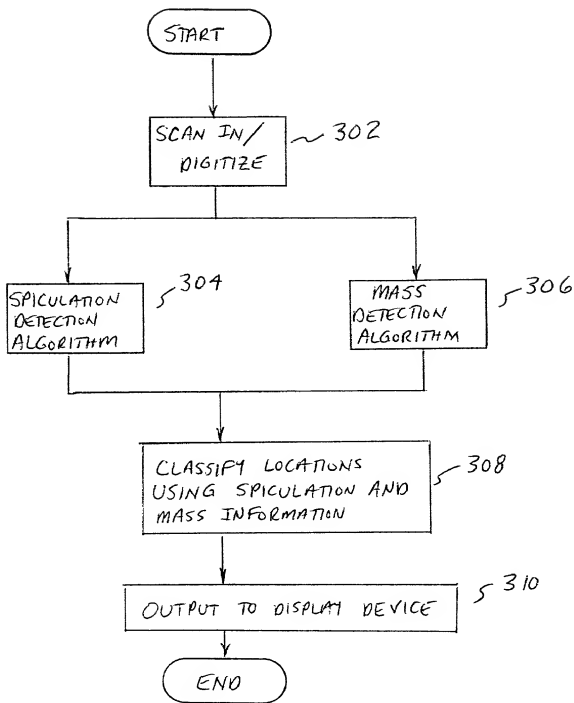
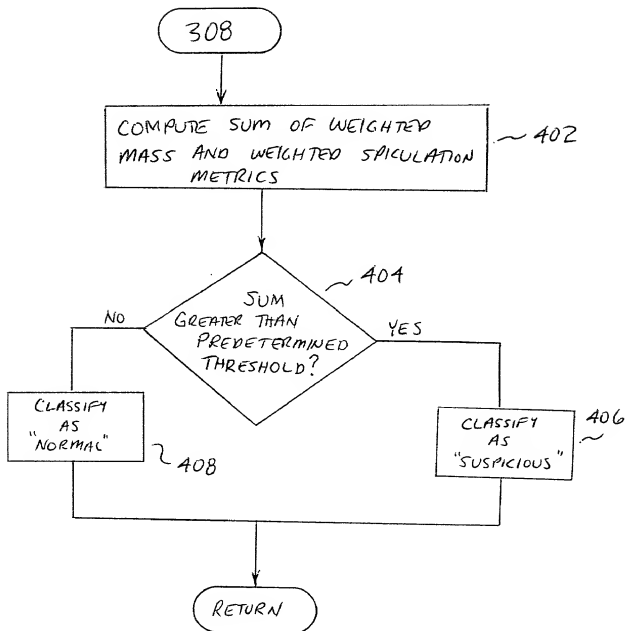


FIG. 3



COMPUTE SUM OF WEIGHTED
MASS AND WEIGHTED SPICULATION
METRICS

402

SUM
GREATER THAN
PREDETERMINED
THRESHOLD?

404

No

YES

CLASSIFY
"AS
NORMAL"

2408

CLASSIFY
AS
"SUSPICIOUS"

406

RETURN

FIG. 4

**DECLARATION
AND POWER OF ATTORNEY**

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below at 201 et seq. underneath my name.

I believe I am the original, first and sole inventor if only one name is listed at 201 below, or an original, first and joint inventor if plural names are listed at 201 et seq. below, of the subject matter which is claimed and for which a patent is sought on the invention entitled

**METHOD AND SYSTEM FOR DETECTION OF SUSPICIOUS LESIONS IN DIGITAL MAMMOGRAMS USING A
COMBINATION OF SPICULATION AND DENSITY SIGNALS**

and for which a patent application:

- ☒ is attached hereto and includes amendment(s) filed on _____ (if applicable)
☐ was filed in the United States on _____ as Application No. _____ (for declaration not accompanying application)
with amendment(s) filed on _____ (if applicable)
☐ was filed as PCT International Application No. _____ on _____ and was amended under PCT Article 19 on _____ (if applicable)

I hereby state that I have reviewed and understand the contents of the above identified application, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

EARLIEST FOREIGN APPLICATION(S), IF ANY, FILED PRIOR TO THE FILING DATE OF THE APPLICATION			
APPLICATION NUMBER	COUNTRY	DATE OF FILING (day, month, year)	PRIORITY CLAIMED
			YES <input type="checkbox"/> NO <input type="checkbox"/>
			YES <input type="checkbox"/> NO <input type="checkbox"/>

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States provisional application(s) listed below.

APPLICATION NUMBER	FILING DATE

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

APPLICATION SERIAL NO.	FILING DATE	STATUS		
		PATENTED	PENDING	ABANDONED
09/103,290	6/23/98		X	
08/676,660	7/10/96		X	

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